

Wireless System Images Complex Shale

By Marty Williams
and Kevin Drake

HOUSTON—Explorationists for Pittsburgh-based operator East Resources Inc. are relying on interpretations of multi-component seismic data to drill a series of wells in the hard-to-image intersecting fractures of the Niobrara Shale. The Niobrara play is a potentially giant oil resource play in the Rocky Mountains of Colorado, Wyoming and New Mexico that has re-emerged as a primary oil target because of new imaging, drilling and completion technologies.

East Resources was the primary underwriter of a multicient seismic program acquired in Moffat County in northwestern Colorado. In this area, the Niobrara underlies rugged mountains and a mix of environmentally sensitive public and private lands. The Durham Ranch seismic survey was carried out under a rigid schedule and project management strategy using a cableless land seismic system that incorporates digital multicomponent sensors.

Despite daunting operational and imaging challenges, the seismic contractor was able to acquire 9.2 million traces of

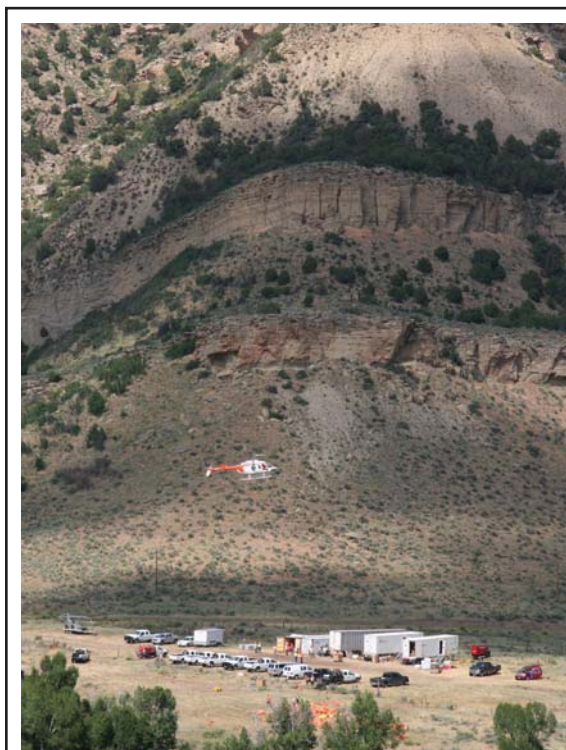
seismic data in only 45 days from the moment of deployment. The time span, from first shot to last, was a mere 20 days. In fact, the preliminary data were delivered to East Resources only 45 days after field operations with the wireless acquisition system were concluded at Durham Ranch.

As a result of the accelerated acquisition and advanced imaging methods employed, East Resources was able to understand, identify and target multiple well locations for 2009 permitting within the Niobrara petroleum system.

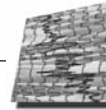
The data are continuing to be processed, and by the time the drilling permits are approved, East Resources expects to have even better data in hand. Final seismic data are unlikely to prompt the company to change any surface locations, but may allow it to more precisely target the high-angle or horizontal wells that will likely be needed to properly develop the fractured shale reservoirs.

The Durham Ranch survey marked the first commercial deployment of the cableless land acquisition system. The cableless system was created to resolve the numerous limitations of cable-based seismic acquisition technology and was the first cableless land acquisition system to incorporate multicomponent (full-wave) seismic sensor technology.

The cableless system was developed in 2003 with four fundamental objectives: to advance seismic imaging, increase productivity, reduce overall cycle time, and decrease the overall environmental impact of land seismic surveys. Each of these factors, driven by insights from early field trials with BP and Apache Corporation in late 2006 and early 2007, played



Despite daunting operational and imaging challenges, 9.2 million traces of seismic data were acquired on the Durham Ranch survey from 6,100 field station units deployed over 30 square miles.



key roles in contributing to the operational success at Durham Ranch.

Structural Complexity

The Durham Ranch survey area is located within the Niobrara total petroleum system, which is described by the U.S. Geological Service as a 4,600-square-mile Upper Cretaceous formation located in northwestern Colorado and southwestern Wyoming that produces oil and natural gas from fractured carbonate reservoirs.

Deposited during a major Late Cretaceous marine transgressive cycle, the Niobrara ranges in thickness from 900 to 1,800 feet. The Niobrara continuous oil assessment unit in the southeastern part of the province consists mainly of interbedded organic-rich shale, calcareous shale, shaley limestone and marl. The fine-grained nature of these lithologies provides very little matrix porosity or permeability, and as a result production is dependent on fractures.

According to the USGS, most productive Niobrara wells produce from fractured reservoirs associated with Laramide-age or later folding and faulting. Production from fractures also occurs along the crests of anticlines as well as down the steep and gentle flanks, where production is independent of structural closure. Previous detailed fracture studies of outcrops and subsurface rocks in northwestern Colorado have determined that Niobrara fractures are mineralized, with calcite, quartz or gypsum partially lining or completely plugging fracture systems. The best wells producing from the Niobrara to date intersect, or are in close proximity, to normal faults or fractures associated with Neogene-age extensional features where calcite lines—rather than plugs—fractures.

The geology in the survey area is very complex structurally, with steep dips, folding and local but intense fracturing. There are some foreland structures, probably of Eocene age and earlier, that can be quite large. Some of the initial wells that penetrated those structures produced more than 2,000 barrels of oil a day when they were discovered in the 1920s.

Finding The 'Swarms'

The objective of East Resources' redevelopment program is to find intersections, or "swarms," of fractures associated with faults and fault systems possibly formed during post-Laramide Neogene extension. USGS reports Niobrara wells have produced

The comprehensive command-and-control software system deployed at Durham Ranch managed numerous aspects of surveying operations, including GIS data management (for hazard and access), production reporting, quality control and mapping, and in-field station deployment and pickup. GPS capability within the system also created a powerful HS&E resource by enabling project managers to preplan daily work flows and issue assignments, instructions and safe route requirements to field crews through preprogrammed handheld navigation devices.



oil from fractured shale occurring at depths as shallow as 3,000 feet and as deep as 9,000 feet. Fractured shale reservoir zones typically range from 50 to 200 feet in thickness, according to the agency, but may be as much as 400 feet thick in some wells.

Acquiring data that can image both shallow and deep objectives with a single seismic acquisition system requires source and receiver points to be closely spaced to sample shallow strata and with long offsets to sample deep objectives. As a result of the requirement to deploy so many receivers, the capabilities of conventional cable-based acquisition systems are challenged. In the past, convention frequently held that it was more effective and less costly to shoot a survey twice than to design for both shallow and deep objectives in a single survey.

Even in the best of circumstances, acquiring seismic data on both shallow and deep strata with a cable system makes for time-consuming, extremely expensive seismic, because it requires a lot of equipment and a lot of people to move that equipment around. The acquisition objectives at Durham Ranch were even more challenging because of the subtlety of the faults and fracture systems necessary to image and the extremely short timeline within which the crew was required to act.

Wildlife closures and the financially lucrative hunting season limited the time window. Acquisition operations cannot begin within half a mile of an active raptor nest until raptor nesting season ends, generally around Aug. 15. Moreover, operations need to be complete before

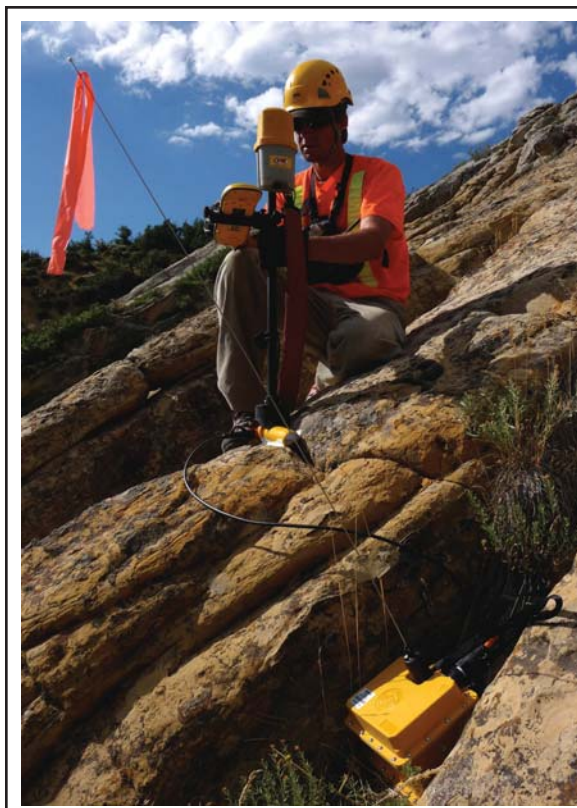
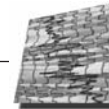
the start of hunting season on Sept. 1. The program was designed to accommodate these constraints, with the initial shots being taken in the nonraptor areas in mid-July and the final shots being taken 45 days later, several days ahead of the opening of the hunting season.

Ground Control

Cableless architecture helps control the cost of sampling both shallow and deep seismic attributes in one survey. For the Durham Ranch project, the cableless system that was used enabled the seismic data acquisition company to efficiently deploy 6,100 field station units (FSUs) in the 30-square-mile survey area—far more receiver stations than would have been possible using a cable-based system, considering the time constraints and rugged topography.

Similarly, the 9.2 million traces of seismic data acquired was nearly six times greater than the level of sampling possible using conventional 3-D cabled acquisition methods under the same time constraints and topographical challenges. In all, the Durham Ranch survey consisted of 10,597 receiver points and 6,763 dynamite shot points. Source and receiver density was 346 per square mile, and the live patch covered almost nine square miles.

One of the major differences between this system and other cableless systems is that it is tightly integrated with a comprehensive command-and-control software system designed to improve field operations, crew planning and data management. The software was created specifically to



Despite the rugged mountainous terrain with extremely variable topography, cable-free recorder stations were able to be placed wherever called for to best acquire data throughout the Durham Ranch survey area. In fact, the surface relief was so extreme that climbing crews deployed some of the multicomponent sensors on the faces of sheer rock cliffs by gluing them in place with a biodegradable epoxy.

help manage the new operational workflows created as a result of next-generation cableless acquisition technology and multicomponent seismic sensors. The system managed many aspects of the Durham Ranch project, including GIS data management (for hazard and access), production reporting, quality control and mapping, and in-field station deployment and pickup.

The global positioning system capability within the system creates a powerful health, safety and environment resource by enabling project managers to preplan daily work flows and issue assignments, instructions and safe route requirements to crews working in the field through preprogrammed handheld navigation devices. When crew members arrive each morning, they can be issued navigation tools containing all that day's work instructions. As the crews perform their work, if any crew members encroach on a restricted area (areas deemed either an environmental or safety risk), the navigation tool warns them immediately.

After surveying is halted for the day, each work group downloads information from its navigation device into a navigation server. The project manager then can assess exactly which tasks have been accomplished and assign objectives for the next day. Also, if any crew had entered a

restricted area that day, the project manager will be able to view the crew's daily location history.

The system also allows tolerances for various acquisition activities to be preset, and tolerances to be adjusted in the field as conditions change. If anything falls outside of those preset tolerances a warning will be issued. Made aware of the incident, the operator can enter instructions in the navigation tool for a crew to address the issue. This attention to detail helps improve efficiency and reduce cycle time by enabling tasks that occur in a linear or sequential fashion on conventional cable acquisitions to proceed in parallel or occur simultaneously on a cableless survey.

Operational Challenges

The mountainous terrain encompassing the Durham Ranch survey area exhibits extremely variable topography, with cliffs and buttes protruding out of high mountain meadows. Yet planners were able to place cable-free recorder stations wherever called for to best acquire data. So extreme was surface relief that climbing crews deployed some of the digital, multicomponent sensors (which are tilt-insensitive) on the faces of sheer rock cliffs by gluing them in place with a biodegradable epoxy.

The remote, environmentally sensitive Durham Ranch area is home to numerous

species of wildlife. Part of the survey area is on public lands, while privately owned acreage within survey boundaries hosts numerous ranching operations and farms with irrigated fields. East Resources had to get permission from the U.S. Bureau of Land Management, special interest groups and private land owners—most of whom really did not understand nor want oil drilling in the area—to gain access to the survey location. The acquisition was quite complex from an access standpoint, which could be why no other seismic surveys had been conducted in the area in recent history. In fact, the most recent seismic data that had been shot in the region was 2-D data acquired during the 1980s.

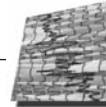
East Resources felt it needed to be very sensitive to the local stakeholders and fly under the radar as much as possible during the Durham Ranch survey. The impact of the cableless system in the survey area was so minimal that some of the ranchers in the area asked when the crew was going to lay out the seismic equipment; they did not even realize it was going on at the time. Positive environmental demonstrations like the one at Durham Ranch should help geophysical contractors as well as oil and gas producers recognize the value created by full-wave seismic data and cableless acquisition technology.

Imaging Fractured Reservoirs

New seismic processing methods have been developed to enable geoscientists to map fracture patterns and associated permeability changes, which allows operators to better target highly productive zones within complex-to-image, heterogeneous reservoirs.

An essential aspect of imaging fractured reservoirs is to acquire high-quality measurements of the subsurface that can detect both fracture density and fracture orientation. These fracture features can be inferred indirectly by characterizing the azimuthal variations in seismic velocity (anisotropy) within the target formation. Additionally, in a vertically fractured zone, the amplitude variation with offset (AVO) response will vary in relation to the degree of alignment of the seismic wave with the azimuth of the fracture system. The greatest variation will occur between AVO responses parallel and perpendicular to the dominant fracturing direction.

One of the more elegant techniques that have been applied to the data is an anisotropic, prestack, offset vector tile (OVT) migration that preserves azimuthal properties for fracture detection in the



presence of complex structure. By combining OVT with the azimuthal velocity analysis, the subtleties of the reservoir structure and fracture system are able to be imaged far better than what was possible with traditional prestack migration and sectorized fracture analysis.

So far, the seismic data that has been acquired is dense enough to image the subtle fracture systems. Although only the compressional wave data has been imaged so far, the available images have provided a much greater understanding of the dynamics of the reservoir and highlighted excellent drilling locations for the 2009 drilling season.

At Durham Ranch, multiple technologies combined to contribute to the success of the project. Cycle time reduction and low-impact operations resulted from the inherent efficiency of a cableless seismic

acquisition system and the automation of the deployment, shooting and retrieval operations made possible by the software-based command-and-control system. Image quality improvements were made possible by the design of a high-density survey, high-fidelity 3-C sensors, and the application of advanced processing methods that take into account anisotropy within the reservoir interval.

Having access to a flexible land acquisition system that can provide the operational efficiencies shown at Durham Ranch can prove highly beneficial, particularly during tough economic times. From an operational and imaging perspective, significantly reducing acquisition and data processing time brings seismic into the hands of decision makers faster, compressing the total time needed to identify and develop prospects. □

MARTY WILLIAMS is a geophysicist at East Resources Inc., a private independent oil and gas company that works mainly in the Appalachian Basin and Rocky Mountains. He began his career as a geologist at Amoco Production Company in 1982. After receiving an M.S. in geophysics in 1984, he rejoined Amoco as geophysicist for an additional 14 years, at which point he co-founded AXIS Geophysics. After selling the company in 2003, Williams stayed on to join Input Output, where he was senior vice president for Full Wave Technologies. He has obtained patents and received awards in both anisotropic processing and cableless acquisition systems.

KEVIN DRAKE is the director of FireFly™ operations for ION Geophysical Corp., a provider of advanced seismic data acquisition systems. With 25 years of service in the geophysical industry, he has extensive experience with land seismic operations in North America and internationally. Drake joined Western Geophysical (now WesternGeco, a division of Schlumberger) as a field geophysicist in 1984, and remained with the company until 2007, when he joined ION Geophysical.